

Statistical study of the low pressure systems during summer monsoon season over the Indian region

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सार – निम्न अवदाब अथवा चक्रवातीय तूफान के कारण निम्न दाब क्षेत्र के बनने की घटना को निम्न दाब प्रणाली (एल.पी.एस.) का नाम दिया गया है। दक्षिणी पश्चिमी मानसून वर्षा ऋतु के दौरान वर्षा के वितरण में एल.पी.एस. का महत्वपूर्ण योगदान है। छोटे क्षेत्रों तक केन्द्रित वर्षा लाने वाले अवदाबों और चक्रवातीय तूफानों की अपेक्षा निम्नदाब के परिणाम स्वरूप दूर-दूर तक वर्षा होती है। वर्षा का वितरण एल.पी.एस. के मार्ग और जीवन काल पर निर्भर करता है। अधिकांश एल.पी.एस. बंगाल की खाड़ी में बनते हैं और उत्तरी पश्चिमी दिशा से होते हुए देश के अधिकांश भागों में वर्षा की सक्रियता को सुदृढ़ करते हैं। इस शोध-पत्र में भारत, पाकिस्तान, बंगलादेश, बंगाल की खाड़ी और अरब सागर के भीतर आने वाले क्षेत्रों पर 1891 से 2000 तक की अवधि में जून से सितंबर तक की मानसून वर्षा ऋतु के दौरान बने एल.पी.एस. पर विचार किया गया है। एल.पी.एस. की अवधि का अध्ययन भी मानसून वर्षा ऋतु के दौरान बने एल.पी.एस. दिनों के रूप में किया गया है। एल.पी.एस. और एल.पी.एस. दिनों का सांख्यिकी विश्लेषण मानसून के महीनों तथा 1891–2000 तक की अवधि के समूचे मानसून वर्षा के लिए किया गया है। यह देखा गया है कि मानसून के किसी भी महीने में एल.पी.एस. की आवृत्ति छः से अधिक नहीं बढ़ती किन्तु एक महीने में तीन एल.पी.एस. का होना प्रायः सामान्य बात है। मानसून वर्षा ऋतु के दौरान एल.पी.एस. का होना प्रायः सामान्य बात है। मानसून वर्षा ऋतु के दौरान एल.पी.एस. की कुल संख्या 9 से 18 के बीच होती है। जून से जुलाई के महीने में एल.पी.एस. की अधिकतम कुल अवधि 10–14 एल.पी.एस. दिनों के बीच होती है जबकि अगस्त और सितंबर में यह 15–19 एल.पी.एस. दिनों के बीच होती है। अगस्त का महीना सबसे अधिक एल.पी.एस. और एल.पी.एस. दिनों वाला होता है। इनकी आवृत्ति के विश्लेषण से यह पता चलता है कि मासिक और मौसमी एल.पी.एस. और एल.पी.एस. दिन सामान्य रूप से वितरित होते हैं। यह भी ज्ञात हुआ है कि यद्यपि ऋतु के कुल एल.पी.एस. की संख्या में विशेष घट बढ़ नहीं हुई है किन्तु 1971–80 और 1981–90 के दशकों में विशेष रूप से वृद्धि हुई है।

ABSTRACT. The occurrence of a closed low pressure area due to low, depression or cyclonic storm is termed as Low Pressure System (LPS). LPS plays an important role in the distribution of rainfall during the southwest monsoon season. Lows produce widespread rainfall as compared to depressions and cyclonic storms which yield concentrated rainfall over a smaller area. The distribution of rainfall depends upon the track and life span of LPS. Most of the LPS formed over the Bay of Bengal travel in northwest direction strengthening the rainfall activities over the large parts of the country. In this study, the LPS formed during the monsoon season, June to September for the period 1891–2000 over the region covering India, Pakistan, Bangladesh, Bay of Bengal and Arabian Sea are taken into account. The duration of LPS is also studied in terms of LPS Days during the monsoon season. The statistical analysis of LPS and LPS Days is carried out for the monsoon months and for the monsoon season as a whole, for the period 1891–2000. It is seen that the frequency of LPS during any of the monsoon months does not exceed six but three LPS in a month are more common. Total number of LPS during the monsoon season ranges from 9 to 18. In June and July maximum total duration of LPS lies between 10–14 LPS Days while in August and September, it is between 15–19 LPS Days. August is the month having maximum number of LPS and LPS Days. The frequency analysis shows that monthly and seasonal LPS and LPS Days are normally distributed. It is also observed that even though season's total number of LPS has no significant increase or decrease, the LPS Days have significantly increased during the decades, 1971–80 and 1981–90.

Key words – Low Pressure System, LPS, LPS Days.

1. Introduction

Indian economy is largely dependent on the agriculture production which is closely linked with the performance of the summer monsoon rainfall. About 70% of the annual total rainfall of India occurs in the summer monsoon season (hereafter referred as monsoon season), from June to September. The monsoon rainfall shows

large day to day variation within the season. During the monsoon season, there are several semi-permanent and synoptic weather systems like, Monsoon Trough, Off Shore Trough, Tropical Easterly Jet and Low Pressure Systems which affect the distribution of rainfall in various parts of the country. The LPS in the present study includes low, depression or cyclonic/severe cyclonic storm. A low generally produces rainfall over a wider area and persists

TABLE 1

Total number of LPS during the monsoon months and season as a whole over the Indian region for the period 1891-2000

Year	Month				Season	Year	Month				Season	Year	Month				Season
	Jun	Jul	Aug	Sep			Jun	Jul	Aug	Sep			Jun	Jul	Aug	Sep	
1891	2	4	6	4	16	1929	3	4	4	3	14	1967	2	3	4	4	13
1892	2	4	3	3	12	1930	2	3	3	3	11	1968	2	2	3	2	9
1893	2	2	4	3	11	1931	1	1	5	2	9	1969	3	3	3	3	12
1894	3	4	1	4	12	1932	1	4	2	2	9	1970	4	2	5	3	14
1895	4	4	3	3	14	1933	4	4	3	4	15	1971	5	3	3	3	14
1896	3	5	4	1	13	1934	4	3	4	3	14	1972	4	3	3	2	12
1897	3	4	5	3	15	1935	3	4	2	3	12	1973	3	5	4	4	16
1898	1	6	5	3	15	1936	2	3	4	2	11	1974	4	0	3	4	11
1899	1	4	4	2	11	1937	4	4	2	4	14	1975	5	4	5	4	18
1900	3	3	5	3	14	1938	3	3	4	1	11	1976	3	2	3	2	10
1901	1	4	5	2	12	1939	1	4	3	4	12	1977	3	5	3	3	14
1902	4	5	3	3	15	1940	2	2	4	2	10	1978	4	4	4	3	15
1903	2	5	5	3	15	1941	5	4	3	3	15	1979	3	4	4	6	17
1904	6	4	4	3	17	1942	5	5	4	3	17	1980	5	4	3	4	16
1905	3	5	1	6	15	1943	2	6	3	4	15	1981	4	4	4	4	16
1906	3	3	2	4	12	1944	3	4	5	4	16	1982	2	4	6	2	14
1907	6	1	5	2	14	1945	2	3	1	4	10	1983	2	4	3	4	13
1908	3	3	5	3	14	1946	2	4	5	3	14	1984	4	2	5	3	14
1909	2	5	1	4	12	1947	3	4	3	4	14	1985	4	1	5	4	14
1910	4	1	3	5	13	1948	2	3	5	4	14	1986	2	4	4	2	12
1911	2	1	3	5	11	1949	1	3	4	3	11	1987	3	2	4	3	12
1912	1	3	2	4	10	1950	3	3	4	3	13	1988	4	2	3	3	12
1913	4	4	3	3	14	1951	3	3	3	1	10	1989	4	3	6	2	15
1914	3	5	2	2	12	1952	3	5	3	4	15	1990	2	3	5	4	14
1915	2	2	2	4	10	1953	2	0	4	3	9	1991	2	3	5	2	12
1916	3	2	3	2	10	1954	2	3	2	5	12	1992	2	3	3	2	10
1917	4	2	3	2	11	1955	4	2	5	5	16	1993	3	4	4	5	16
1918	3	1	3	3	10	1956	4	4	3	2	13	1994	4	6	5	2	17
1919	2	4	6	2	14	1957	0	4	4	2	10	1995	1	2	4	4	11
1920	2	5	2	3	12	1958	0	6	2	3	11	1996	3	4	4	3	14
1921	3	2	5	6	16	1959	2	3	6	3	14	1997	2	2	3	2	9
1922	2	4	4	5	15	1960	2	2	4	4	12	1998	3	4	1	3	11
1923	1	4	4	4	13	1961	3	6	4	4	17	1999	3	3	3	3	12
1924	3	2	5	3	13	1962	2	5	3	3	13	2000	3	3	3	4	13
1925	3	3	2	2	10	1963	3	2	3	3	11	Total	308	371	396	352	1427
1926	1	3	3	5	12	1964	3	1	5	3	12	Mean	2.8	3.4	3.6	3.2	13.0
1927	2	5	4	2	13	1965	3	5	4	2	14	S.D.	1.2	1.3	1.2	1.1	2.2
1928	5	4	3	5	17	1966	3	3	1	3	10	% of Total	21.6	26.0	27.7	24.7	-

TABLE 2

Total number of LPS Days during the monsoon months and season as a whole over the Indian region for period 1891-2000

Year	Month				Season	Year	Month				Season	Year	Month				Season
	Jun	Jul	Aug	Sep			Jun	Jul	Aug	Sep			Jun	Jul	Aug	Sep	
1891	4	15	29	27	75	1929	12	24	26	6	68	1967	5	8	16	22	51
1892	10	20	8	22	60	1930	4	24	8	15	51	1968	12	11	20	10	53
1893	19	6	19	22	66	1931	2	5	18	12	37	1969	8	10	13	20	51
1894	17	23	8	15	63	1932	6	18	8	17	49	1970	12	14	13	24	63
1895	21	13	15	15	64	1933	13	16	19	26	74	1971	23	15	16	10	64
1896	16	18	17	7	58	1934	14	9	20	12	55	1972	8	13	28	16	65
1897	13	15	19	12	59	1935	5	17	7	9	38	1973	12	23	23	19	77
1898	7	21	25	10	63	1936	11	14	12	6	43	1974	13	0	15	16	44
1899	3	12	14	10	39	1937	15	13	9	18	55	1975	19	13	27	13	72
1900	13	10	32	19	74	1938	10	10	8	5	33	1976	13	13	24	23	73
1901	4	14	20	13	51	1939	3	14	24	18	59	1977	27	18	19	18	82
1902	15	20	13	16	64	1940	5	12	22	10	49	1978	12	15	28	25	80
1903	5	18	15	12	50	1941	11	15	19	10	55	1979	14	14	21	20	69
1904	17	17	18	17	69	1942	7	21	15	17	60	1980	26	18	19	18	81
1905	6	25	4	24	59	1943	3	23	12	17	55	1981	11	13	21	24	69
1906	11	11	7	17	46	1944	9	19	32	10	70	1982	9	14	28	18	69
1907	24	2	24	6	56	1945	5	16	3	18	42	1983	12	18	18	19	67
1908	13	11	25	13	62	1946	8	15	16	15	54	1984	22	9	32	13	76
1909	7	18	6	17	48	1947	10	15	19	26	70	1985	10	9	26	22	67
1910	9	10	10	20	49	1948	9	13	19	19	60	1986	10	22	22	10	64
1911	17	3	16	22	58	1949	2	9	11	16	38	1987	11	8	21	20	60
1912	4	7	14	11	36	1950	10	10	15	15	50	1988	23	10	16	26	75
1913	11	20	18	13	62	1951	6	9	12	5	32	1989	20	19	30	13	82
1914	15	17	8	15	55	1952	11	23	18	12	64	1990	17	11	26	20	74
1915	7	6	12	12	37	1953	9	7	17	15	48	1991	10	15	25	11	61
1916	14	3	17	11	45	1954	3	9	11	24	47	1992	10	9	10	18	47
1917	19	4	16	14	53	1955	15	11	15	23	64	1993	16	13	11	23	63
1918	10	4	18	10	42	1956	15	15	17	7	54	1994	19	24	25	14	82
1919	9	13	29	6	57	1957	0	8	13	14	35	1995	3	8	12	22	45
1920	10	15	12	17	54	1958	0	20	10	19	49	1996	19	12	14	9	54
1921	9	11	13	25	58	1959	11	19	16	16	62	1997	11	14	25	9	59
1922	8	22	16	25	71	1960	2	7	24	13	46	1998	15	18	4	20	57
1923	3	10	23	10	46	1961	18	18	13	31	80	1999	10	12	21	27	70
1924	5	4	20	18	47	1962	7	26	8	20	61	2000	12	19	20	15	66
1925	14	18	8	12	52	1963	11	5	10	15	41	Total	1195	1524	1866	1765	6350
1926	1	16	15	26	58	1964	10	6	18	15	49	Mean	10.9	13.9	17.0	16.0	57.7
1927	9	22	23	5	59	1965	4	22	11	15	52	S.D.	5.8	5.7	6.8	5.7	12.0
1928	16	19	11	17	63	1966	10	12	5	14	41	% of Total	18.8	24.0	29.4	27.8	-

for longer duration evidently the frequency of lows is more than the frequency of depressions, cyclonic and severe cyclonic storms.

Most of the LPS of the monsoon season form over the Bay of Bengal. Very few of them form over the Arabian Sea or land areas. Here all LPS forming over the Bay of Bengal, Arabian Sea and Land areas are taken into account. A large number of LPS formed over the Bay of Bengal travel in north-west direction producing good rainfall over the central parts of the country. These LPS play an important role in maintaining the normal position of the monsoon trough. LPS forming over the Arabian Sea travel in north or north-east direction producing rainfall over the western parts of the country. Longer duration of LPS is favourable for the enhanced rainfall.

A lot of work has been done on cyclonic disturbances such as depressions and cyclonic storms. Many researchers like, Pisharoty and Asnani (1957), Lal (1958), Rao and Jayaraman (1958), Raghavan (1965), Mooley (1973), Sikka (1977), Joseph (1981) and Saha *et al.* (1981) have extensively studied the influence of storms/depressions on the performance of monsoon rainfall. Dhar *et al.* (1981) examined the influence of tropical disturbances (*i.e.* storms/depressions) on monthly rainfall and season's total rainfall for India as a whole. Mooley and Shukla (1987) have examined some characteristic features of LPS in terms of formation, location, movement and duration of LPS. They found significant relationship (at 1% level) between LPS Days during the monsoon season and central India monsoon rainfall. Jadhav (2002) studied the influence of low pressure systems over the sub-divisional monsoon rainfall. He observed some significant relationships between monthly LPS Days in a specific grid (5° Lat. \times 5° Long.) location over the Indian region and monthly sub-divisional rainfall.

The objective of this paper is to carry out statistical analysis of LPS, which may be of some use for synopticians and researchers in their work.

2. Data and data analysis

Daily locations of LPS formed over the Indian region for the period 1891-1983 are obtained from the Research Report by Mooley and Shukla (1987) and daily locations of LPS for the period 1984-2000, are collected from 3 UTC charts of Indian Daily Weather Reports (IDWR), India Meteorological Department (IMD), Pune.

LPS term includes lows, depressions, cyclonic storms or severe cyclonic storms. The LPS existing over the Indian region covering India, Pakistan and Bangladesh, Bay of Bengal, Arabian Sea are considered

for this study. The daily locations and intensities of LPS give the track of the respective LPS. The procedure adapted for identifying the LPS is taken from the Research Report by Mooley and Shukla (1987).

The total number of LPS are computed from the daily locations of LPS during the monsoon months June to September and during the total monsoon season for the period 1891-2000. Table 1 shows monthly and seasonal total number of LPS for the period 1891-2000. For the frequency distribution of LPS, the number of LPS are counted to the month in which they are commencing though they continue to persist in the next month.

From the daily locations of LPS, duration of the LPS is counted in terms of LPS Days. The Days for which LPS exists over a particular location in any monsoon month over the Indian region are the LPS Days of that month. If there are more than one LPS occurring simultaneously then their LPS Days are counted separately. The total number of LPS Days are computed for the monsoon months June to September and for the monsoon season for the period 1891-2000 (Table 2).

3. Statistical analysis

The statistical analysis is carried out for LPS and LPS Days (Tables 1 & 2). Long term and decadal mean, standard deviation (SD) and coefficient of variation in percentage (CV) are computed for the monsoon months June to September and for the monsoon season as a whole.

3.1. Monthly occurrences of LPS and LPS Days

It is seen that monthly occurrences of LPS during the monsoon months are restricted between 0 to 6. There are total four events of zero LPS in June and July. In August and September there is at least one LPS in a month. There is not a single occasion when the number of LPS during any monsoon month is 7 or above.

The number of monthly LPS Days ranges from 0 to 32. In June and July, there are total three events without LPS Days and the chances of LPS Days above 25 are rare. In August and September there are only five occasions when the LPS Days are 30 or more.

The highest number of LPS and LPS Days have occurred in August.

3.1.1. June

The average number of LPS during the month of June is 2.8 with CV, 41.9. The occurrence of three LPS in a month is more frequent. There are two occasions having

TABLE 3

Decadal frequency distribution of the occurrences of LPS for the monsoon months

No. of LPS	1891-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	1891-2000
June												
0	0	0	0	0	0	0	2	0	0	0	0	2
1	2	1	1	2	3	1	0	0	0	0	1	11
2	3	2	4	3	2	4	4	3	0	4	3	32
3	4	3	3	4	2	3	2	6	4	1	5	37
4	1	2	2	0	3	0	2	1	3	5	1	20
5	0	0	0	1	0	2	0	0	3	0	0	6
6	0	2	0	0	0	0	0	0	0	0	0	2
July												
0	0	0	0	0	0	0	1	0	1	0	0	2
1	0	2	2	0	1	0	0	1	0	1	0	7
2	1	0	3	2	1	0	2	3	1	3	2	18
3	1	2	1	3	3	4	3	3	2	2	4	28
4	6	2	2	4	5	4	2	0	4	4	3	36
5	1	4	2	1	0	1	1	2	2	0	0	14
6	1	0	0	0	0	1	1	1	0	0	1	5
August												
0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	0	0	0	1	0	1	0	0	1	6
2	0	1	4	1	3	0	2	0	0	0	0	11
3	2	2	5	3	2	3	3	4	6	2	4	36
4	3	1	0	4	4	3	3	3	3	3	3	30
5	3	4	0	2	1	3	1	2	1	3	2	22
6	1	0	1	0	0	0	1	0	0	2	0	5
September												
0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	0	0	0	3
2	1	2	4	2	4	0	2	2	2	3	4	26
3	6	4	3	3	2	5	3	6	3	3	3	41
4	2	2	2	1	3	5	2	2	4	4	2	29
5	0	1	1	3	0	0	2	0	0	0	1	8
6	0	1	0	1	0	0	0	0	1	0	0	3

TABLE 4

Decadal frequency distribution of the grouped LPS Days for the monsoon months

No. of LPS	1891-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	1891-2000
June												
0-4	2	1	1	3	2	2	4	1	0	0	1	17
5-9	1	4	2	4	3	5	2	3	1	1	0	26
10-14	3	2	4	2	4	3	2	5	5	5	5	40
15-19	3	2	3	1	1	0	2	1	1	1	4	19
20-24	1	1	0	0	0	0	0	0	1	3	0	6
25-29	0	0	0	0	0	0	0	0	2	0	0	2
30-34	0	0	0	0	0	0	0	0	0	0	0	0
July												
0-4	0	1	4	1	0	0	0	0	1	0	0	7
5-9	1	0	2	0	2	1	5	3	0	3	2	19
10-14	3	4	1	2	5	2	1	4	4	4	4	34
15-19	3	3	2	3	3	5	2	1	4	2	3	31
20-24	3	1	1	4	0	2	2	1	1	1	1	17
25-29	0	1	0	0	0	0	0	1	0	0	0	2
30-34	0	0	0	0	0	0	0	0	0	0	0	0
August												
0-4	0	1	0	0	0	1	0	0	0	0	1	3
5-9	2	2	1	2	4	0	0	2	0	0	0	13
10-14	1	2	3	2	1	2	4	5	0	0	4	24
15-19	4	2	5	2	2	6	5	2	4	2	0	34
20-24	0	2	0	3	3	0	1	1	3	3	2	18
25-29	2	1	1	1	0	0	0	0	3	3	3	14
30-34	1	0	0	0	0	1	0	0	0	2	0	4
September												
0-4	0	0	0	0	0	0	0	0	0	0	0	0
5-9	1	1	1	2	3	0	2	0	0	0	2	12
10-14	3	3	6	2	3	2	3	2	2	3	2	31
15-19	3	4	2	3	3	7	3	3	5	2	2	37
20-24	2	2	1	0	0	0	2	4	2	4	3	20
25-29	1	0	0	3	1	1	0	0	1	1	1	9
30-34	0	0	0	0	0	0	0	1	0	0	0	1

TABLE 5

Season's total number of LPS (xi) and their decadal frequency of occurrence (fi) with decadal total (fixi) given in brackets

Decade LPS (xi)	1891- 1900 fi(fixi)	1901- 1910 fi(fixi)	1911- 1920 fi(fixi)	1921- 1930 fi(fixi)	1931- 1940 fi(fixi)	1941- 1950 fi(fixi)	1951- 1960 fi(fixi)	1961- 1970 fi(fixi)	1971- 1980 fi(fixi)	1981- 1990 fi(fixi)	1991- 2000 fi(fixi)	1891- 2000 $\Sigma fi(\Sigma fixi)$
9	0(0)	0(0)	0(0)	0(0)	2(18)	0(0)	1(9)	1(9)	0(0)	0(0)	1(9)	5(45)
10	0(0)	0(0)	4(40)	1(10)	1(10)	1(10)	2(20)	1(10)	1(10)	0(0)	1(10)	12(120)
11	2(22)	0(0)	2(22)	1(11)	2(22)	1(11)	1(11)	1(11)	1(11)	0(0)	2(22)	13(143)
12	2(24)	3(36)	2(24)	1(12)	2(24)	0(0)	2(24)	2(24)	1(12)	3(36)	2(12)	20(240)
13	1(13)	1(13)	0(0)	3(39)	0(0)	1(13)	1(13)	2(26)	0(0)	1(13)	1(13)	11(143)
14	2(28)	2(28)	2(28)	1(14)	2(28)	3(42)	1(14)	2(28)	2(28)	4(56)	1(14)	22(308)
15	2(30)	3(45)	0(0)	1(15)	1(15)	2(30)	1(15)	0(0)	1(15)	1(15)	0(0)	12(180)
16	1(16)	0(0)	0(0)	1(16)	0(0)	1(16)	1(16)	0(0)	2(32)	1(16)	1(16)	8(128)
17	0(0)	1(17)	0(0)	1(17)	0(0)	1(17)	0(0)	1(17)	1(17)	0(0)	1(17)	6(102)
18	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)	1(18)
Total	13.3	139	114	134	117	139	122	125	143	136	125	1427
Mean	13.3	13.9	11.4	13.4	11.7	13.9	12.2	12.5	14.3	13.6	12.5	13

no LPS, *viz.*, in 1957, 1958 and two occurrences of maximum six LPS in the years 1904 and 1907. The total number of LPS during this month is 21.6% of the season's total.

The long term mean number of LPS Days for June is 10.9 with CV 53.1. There are two occasions having no LPS Days, *viz.*, in 1957, 1958 and maximum LPS Days 27 in 1977. The highest occurrences of LPS Days are in the class interval 10-14. The LPS Days contribution of this month is 18.8% to the season's total.

3.1.2. July

During July, the mean number of LPS is 3.4 and CV is 38.5. The occurrence of four LPS in the month of July is more common. There are two occasions having no LPS, *viz.*, in 1953, 1974 and maximum six LPS occurred in five years *i.e.* in 1898, 1943, 1958, 1961 and 1994. This month contributes 26.0% of the season's total LPS.

The mean number of LPS Days during July is 13.8 with CV, 41.4. The modal value of LPS Days lies in the class interval 10-14. There is one occasion having no LPS Days, *i.e.* in 1974 and maximum 26 LPS Days occurred in 1962. This month contributes 24.0% of the season's total LPS Days.

3.1.3. August

The average number of LPS during August is 3.6 and CV is 33.3. The occurrences of three LPS in a month are more frequent. In August there is no occasion without LPS. There are five instances with six LPS in the years, 1891, 1919, 1959, 1982 and 1989. This month has highest contribution with 27.7% to the season's total LPS.

The average number of LPS Days during the month of August is 17.0 with CV 40.0. The modal value of LPS Days lies in the class 15-19. Lowest number of LPS Days *i.e.* three, is observed in 1945 and highest 32 LPS Days are in 1900, 1944 and 1984. This month has highest contribution with 29.4% of the season's total LPS Days.

3.1.4. September

The average number of LPS during September is 3.2 with CV 32.9. In this month occurrences of three LPS are more common. There are three occasions *i.e.* in the years 1905, 1921 and 1979 having six LPS during the month. LPS contribution of this month is 24.7% to the season's total.

The average number of LPS Days during September is 16.0 and CV is 35.8. The modal value of LPS Days lies in the class 15-19. Lowest number of LPS Days are 5 in

TABLE 6

Decadal frequency distribution of the grouped LPS Days for monsoon season

Decade LPS days	1891- 1900	1901- 1910	1911- 1920	1921- 1930	1931- 1940	1941- 1950	1951- 1960	1961- 1970	1971- 1980	1981- 1990	1991- 2000	1891- 2000
31-35	0	0	0	0	1	0	2	0	0	0	0	3
36-40	1	0	2	0	2	1	0	0	0	0	0	6
41-45	0	0	2	0	1	1	0	2	1	0	1	8
46-50	0	4	0	2	2	1	4	1	0	0	1	15
51-55	0	1	3	2	2	3	1	4	0	0	1	17
56-60	3	2	2	3	1	2	0	0	0	1	2	16
61-65	3	2	1	1	0	0	3	2	2	1	2	17
66-70	1	1	0	1	0	2	0	0	1	4	2	12
71-75	2	0	0	1	1	0	0	0	2	2	0	8
76-80	0	0	0	0	0	0	0	1	2	1	0	4
81-85	0	0	0	0	0	0	0	0	2	1	1	4

1927, 1938 and 1951 and highest is 31 in 1961. Contribution of LPS Days during this month is 27.8% to the season's total.

3.2. Occurrence of LPS and LPS Days during the monsoon season as a whole

Average number of LPS during the monsoon season is 13.0 with CV 16.8. There were five occasions with lowest number of LPS *i.e.* 9 LPS in 1931, 1932, 1953, 1968 and 1997 while there was only one occasion in the year 1975 with highest number of 18 LPS. The frequency of occurrence of 14 LPS in monsoon season are more during the hundred and ten years period.

Average number of LPS Days during the monsoon season are 57.7 with coefficient of variation 20.8. The lowest total number of LPS Days were 32 in 1951 and highest total were 82 in 1977, 1989 and 1994.

3.3. Decadal frequency distribution of monthly LPS and LPS Days

The decadal frequency distribution is prepared with monthly occurrences of LPS ranging from 0 to 6. Table 3 gives the frequency distribution of monthly LPS for the decades and also for the total period 1891-2000.

Monthly total number of LPS Days ranges from 0 to 32. Hence the decadal frequency distribution of monthly

LPS Days is prepared with equal class intervals of 5, *viz.*, 0-4, 5-9,..., 30-34. Table 4 gives the decadal frequency distribution of the monthly grouped LPS Days.

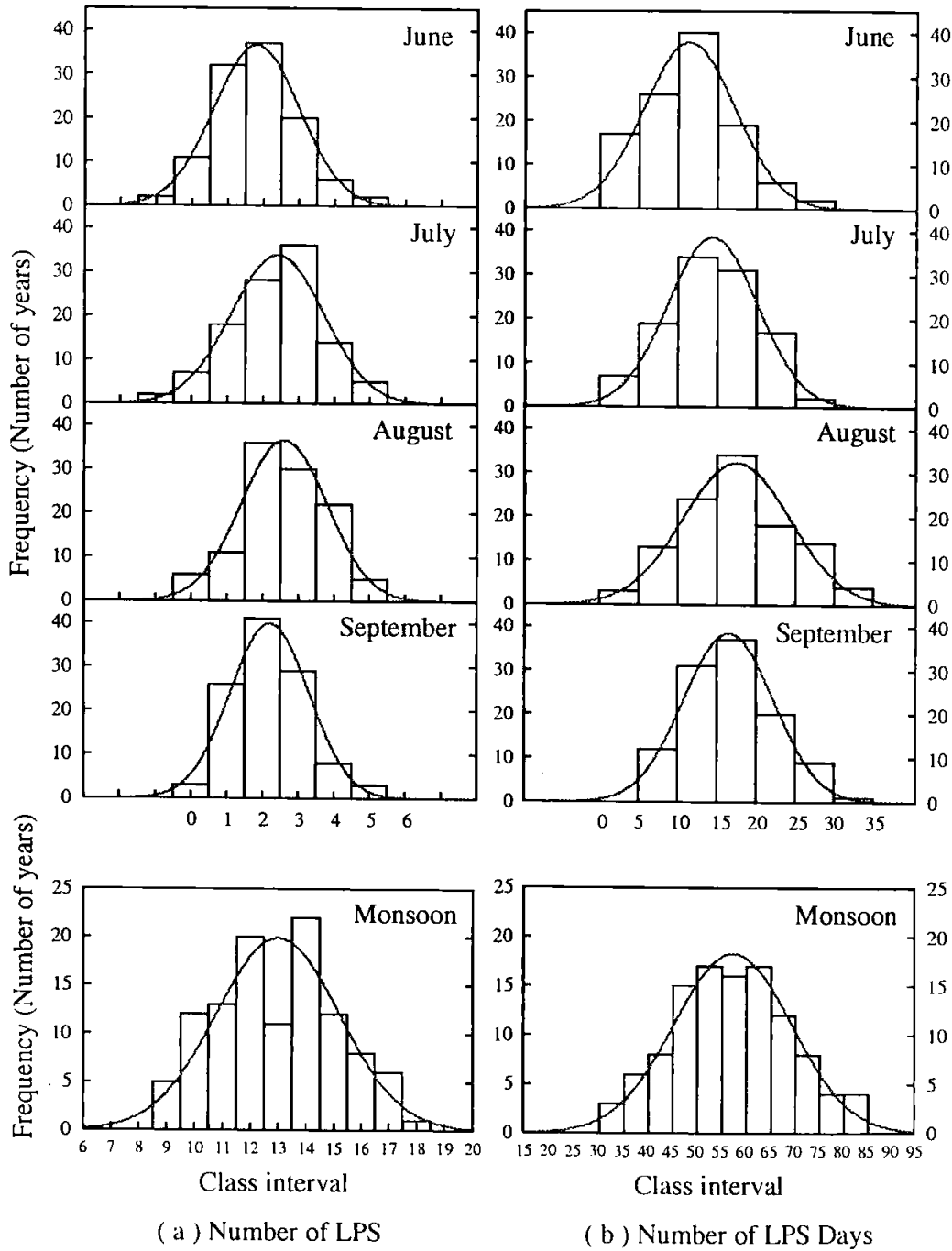
3.4. Decadal frequency distribution of LPS and LPS Days during monsoon season

Total number of LPS ranges from 9 to 18. Hence the decadal frequency distribution of the LPS for the monsoon season is prepared with the unit class interval (Table 5). Total number of LPS Days for monsoon season does not exceed 82. Hence the decadal frequency distribution of the LPS Days for the monsoon season is prepared with equal class intervals 31-35, 36-40,..., 81-85 as shown in Table 6.

3.5. Testing the normality of monthly LPS and LPS Days

Frequency distribution of the monthly LPS and LPS Days are tested for the normality by applying the χ^2 test.

Normal curves are fitted to the frequency distributions of LPS and LPS Days of the monsoon months June to September as shown in Figs. 1(a&b). To test the goodness of fit of normal distribution, the χ^2 test is applied. The χ^2 values are shown in the Tables 7(a&b). In both cases, it is seen that the χ^2 values of frequency distribution of LPS and LPS Days for all the monsoon months, June to September



Figs. 1(a&b). Monthly and seasonal frequency distribution of (a) LPS and (b) LPS days during the period 1891- 2000

are significantly less than the Table value at 5 % level of significance with 4 d.f. (9.49) indicating that the frequency distributions of LPS and LPS Days for all the monsoon months, June to September are normally distributed.

3.6. Testing normality of LPS and LPS Days during the monsoon season

Normal curve fitted to the frequency distribution of LPS during the monsoon season is shown in Figs. 1(a&b).

TABLE 7(a)

Normal curve fitting to the frequency distribution of monthly LPS

No. of LPS	Observed frequency (oi)	Estimated frequency (ei)	(oi-ei) ² /ei	Observed frequency (oi)	Estimated frequency (ei)	(oi-ei) ² /ei
June				July		
0	2	2.4037	0.0678	2	1.1041	0.7269
1	11	11.8724	0.0641	7	6.1413	0.1201
2	32	29.2827	0.2521	18	18.9025	0.0431
3	37	36.0653	0.0242	28	32.1959	0.5468
4	20	22.1806	0.2144	36	30.3461	1.0534
5	6	6.8119	0.0968	14	15.8280	0.0105
6	2	1.0446	0.8737	5	4.5685	0.0100
$\chi^2 = \sum (oi-ei)^2/ei = 1.5932$				$\chi^2 = \sum (oi-ei)^2/ei = 2.7422$		
August				September		
0	0	0.4063	0.4063	0	0.5797	0.5797
1	6	3.4973	1.7909	3	5.3991	1.0660
2	11	15.0343	1.0825	26	22.0033	0.7260
3	36	32.2727	0.4305	41	39.2402	0.0789
4	30	34.5935	0.6099	29	30.6235	0.0861
5	22	18.5165	0.6553	8	10.4582	0.5778
6	5	4.9492	0.0005	3	1.5629	1.3213
$\chi^2 = \sum (oi-ei)^2/ei = 4.9760$				$\chi^2 = \sum (oi-ei)^2/ei = 4.4359$		

TABLE 7(b)

Normal curve fitting to the frequency distribution of monthly LPS Days

Class	Mid point	Observed frequency (oi)	Estimated frequency (ei)	(oi-ei) ² /ei	Observed frequency (oi)	Estimated frequency (ei)	(oi-ei) ² /ei
June				July			
0-4	2	17	11.6558	2.4503	7	4.3546	1.6071
5-9	7	26	30.1761	0.5779	19	18.5010	0.0135
10-14	12	40	37.1564	0.2176	34	36.4142	0.1601
15-19	17	19	21.7597	0.3500	31	33.2024	0.1461
20-24	22	6	6.0607	0.0006	17	14.0247	0.6312
25-29	27	2	0.8029	1.7851	2	2.7444	0.2019
30-34	32	0	0.0506	0.0506	0	0.2488	0.2488
$\chi^2 = \sum (oi-ei)^2/ei = 5.4322$				$\chi^2 = \sum (oi-ei)^2/ei = 3.0086$			
August				September			
0-4	2	3	2.8323	0.0099	0	1.8855	1.8855
5-9	7	13	10.9435	0.3865	12	11.0671	0.0786
10-14	12	24	24.6242	0.0158	31	30.0927	0.0274
15-19	17	34	32.2674	0.0930	37	37.9066	0.0217
20-24	22	18	24.6242	1.7820	20	22.1203	0.2032
25-29	27	14	10.9435	0.8537	9	5.9799	1.5253
30-34	32	4	2.8323	0.4814	1	0.7489	0.0842
$\chi^2 = \sum (oi-ei)^2/ei = 3.6223$				$\chi^2 = \sum (oi-ei)^2/ei = 3.8259$			

TABLES 8(a&b)

Normal curve fitting to the frequency distribution of LPS and LPS Days of monsoon season

No. of LPS	Observed frequency (oi)	Estimated frequency (ei)	(oi-ei) ² /ei	LPS Days class	Mid point	Observed frequency (oi)	Estimated frequency (ei)	(oi-ei) ² /ei
	(a) LPS			(b) LPS Days				
9	5	3.8198	0.3647	31-35	33	3	2.1983	0.2923
10	12	7.8722	2.1645	36-40	38	6	4.7519	0.3278
11	13	13.1953	0.0029	41-45	43	8	8.6345	0.0466
12	20	17.9893	0.2247	46-50	48	15	13.1888	0.2487
13	11	19.9471	4.0132	51-55	53	17	16.9348	0.0003
14	22	17.9893	0.8942	56-60	58	16	18.2791	0.2842
15	12	13.1953	0.1083	61-65	63	17	16.5857	0.0104
16	8	7.8722	0.0021	66-70	68	12	12.6506	0.0335
17	6	3.8198	1.2444	71-75	73	8	8.1113	0.0015
18	1	1.5075	0.1708	76-80	78	4	4.3719	0.0316
				81-85	83	4	1.9809	2.0581
$\chi^2 = \sum(oi-ei)^2/ei = 9.1897$				$\chi^2 = \sum(oi-ei)^2/ei = 3.3350$				

The χ^2 values for testing the normality of the frequency distribution of LPS and LPS Days are shown in Tables 8(a&b) respectively.

The χ^2 value for LPS is 9.19 which fails to attain the 5% significant level with 7 d. f. (14.07). It shows that the number of LPS occurring during the monsoon season are normally distributed. The χ^2 value for LPS Days, is 3.34 which is much less than the 5% level of significance with 8 d.f. (15.51). It shows that the number of occurrences of LPS Days during the monsoon season are normally distributed.

4. Testing the difference between decadal and long term means of LPS and LPS Days

The decadal mean LPS and LPS Days with coefficient of variation for monsoon months and the season as a whole are given in Tables 9(a&b) respectively.

The decadal mean LPS of June ranges from 2.2 to 3.8 and that of July from 2.9 to 4.0. The lowest decadal mean of August is 2.9 and highest one is 4.5 while for September they are 2.7 and 3.8 respectively.

The decadal mean LPS Days of June ranges from 7.2 to 16.7 and for July it ranges from 9.2 to 17.0. Lowest decadal mean of August is 12.7 and highest one is 24.0 while in September they are 13.1 and 18.6 respectively.

The decadal mean LPS and LPS Days for monsoon season as a whole are also shown in Tables 9(a&b). The lowest decadal mean LPS during the monsoon season is 11.4 for the decade 1911-20 and highest one is 14.3 for the decade 1971-80. The lowest decadal mean of LPS Days is 49.2 during the decade 1931-40 and highest one is 70.7 during the decade 1971-80.

Decadal analysis has been carried out to see if any decadal mean is significantly different from long term mean of the period 1891-2000 by applying *t*-test of significance.

4.1. Decadal variation of monthly LPS and LPS Days

It is seen from the Table 9(a), that the decadal mean 4.5 of August for the decade 1981-90, is significantly higher than the long term mean for August. This suggests that the number of LPS in the month of August during the decade 1981-90 has increased significantly.

It is observed from the Table 9(b), that some of the decadal means of the monthly number of LPS Days are significantly different from the long term mean.

In the month of June, mean LPS Days during the decades 1971-80 and 1981-90 are 16.7 and 14.5

TABLE 9(a)

Decadal mean number of LPS over the Indian region during the monsoon season with Standard Deviation (SD) and Coefficient of Variation (CV) for the period 1891-2000

Month Period	June			July			August			September			Season		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1891-1900	2.4	0.9	38.2	4.0	1.0	25.0	4.0	1.3	33.5	2.9	0.8	28.6	13.3	1.7	12.6
1901-1910	3.4	1.6	45.9	3.6	1.5	41.6	3.4	1.6	45.9	3.5	1.2	34.4	13.9	1.6	11.4
1911-1920	2.6	0.9	35.3	2.9	1.4	49.9	2.9	1.1	39.2	3.0	1.0	33.3	11.4#	1.5	13.1
1921-1930	2.5	1.1	44.7	3.4	0.9	27.1	3.7	0.9	24.3	3.8	1.3	34.9	13.4	2.1	15.4
1931-1940	2.5	1.2	48.2	3.2	1.0	30.6	3.3	1.0	30.5	2.7	1.0	37.2	11.7	2.0	17.1
1941-1950	2.8	1.2	44.6	3.9	0.9	24.2	3.7	1.2	32.1	3.5	0.5	14.3	13.9	2.0	14.5
1951-1960	2.2	1.3	60.3	3.2	1.6	50.0	3.6	1.2	33.3	3.2	1.2	39.0	12.2	2.2	17.9
1961-1970	2.8	0.6	21.4	3.2	1.5	48.0	3.5	1.1	31.9	3.0	0.6	21.1	12.5	2.2	17.3
1971-1980	3.8	0.9	22.9	3.4	1.4	42.0	3.5	0.7	19.7	3.5	1.1	31.9	14.3	2.6	18.6
1981-1990	3.1	0.9	30.4	2.9	1.0	36.0	4.5*	1.0	22.8	3.1	0.8	26.8	13.6	1.3	9.4
1991-2000	2.6	0.8	30.8	3.4	1.1	32.8	3.5	1.1	31.9	3.0	1.0	33.3	12.5	2.4	19.3
1891-2000	2.8	1.2	41.9	3.4	1.3	38.5	3.6	1.2	33.3	3.2	1.1	32.9	13.0	2.2	16.8

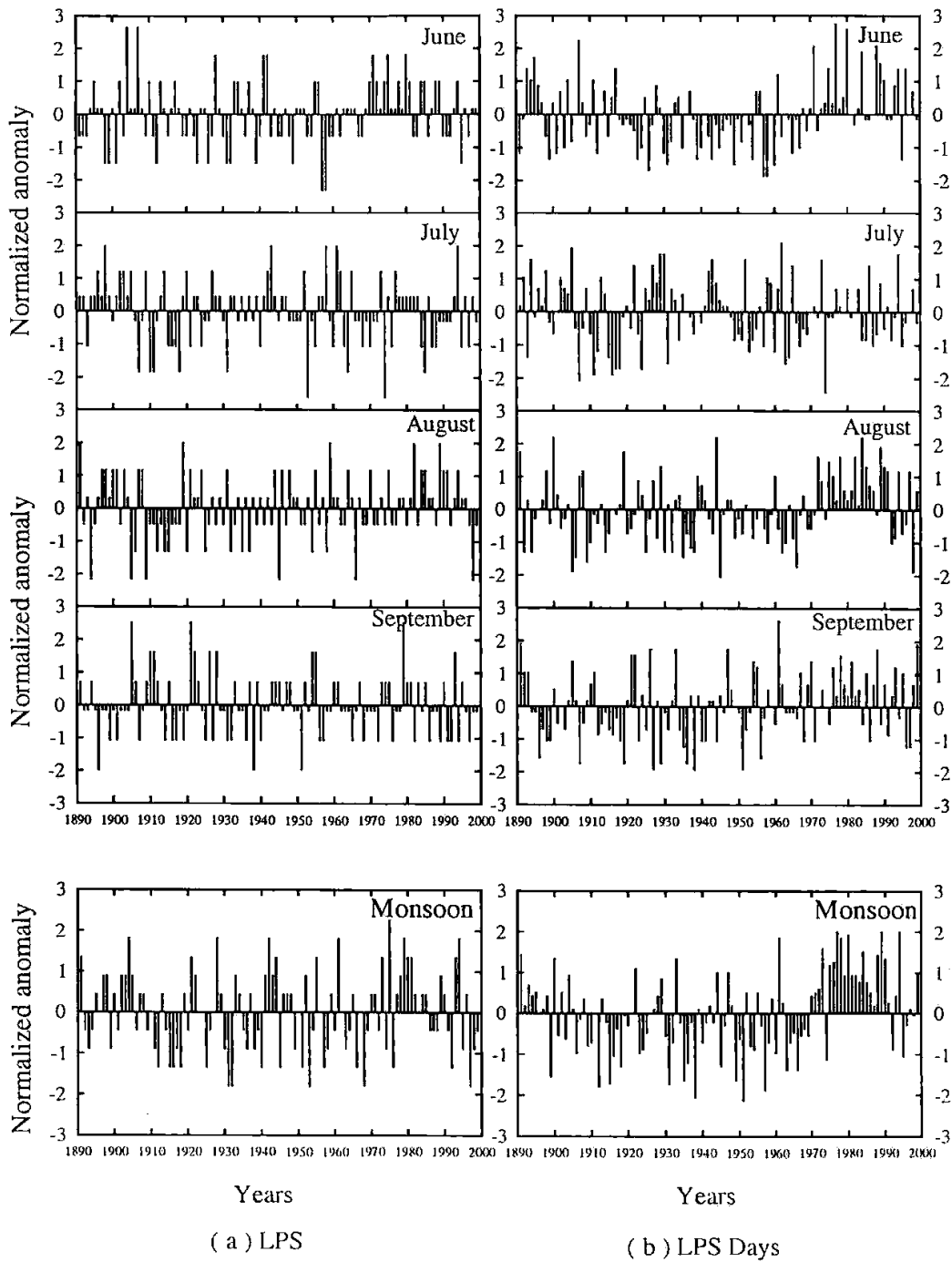
* Significantly increasing, # Significantly decreasing

TABLE 9(b)

Decadal mean number of LPS Days over the Indian region during the monsoon season with Standard Deviation (SD) and Coefficient of Variation (CV) for the period 1891-2000

Month Period	June			July			August			September			Season		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1891-1900	12.3	5.9	48.0	15.3	5.0	32.7	18.6	7.7	41.4	15.9	6.1	38.4	62.1	9.5	15.3
1901-1910	11.1	6.0	53.7	14.6	6.1	41.8	14.2	7.1	50.0	15.5	4.6	29.8	55.5	7.5	13.6
1911-1920	11.6	4.4	37.9	9.2#	6.1	66.3	16.0	5.3	33.1	13.1	4.1	31.3	49.9	8.7	17.4
1921-1930	8.1	4.7	58.0	17.0	6.4	37.6	16.3	6.1	37.4	15.9	7.3	45.9	57.3	8.0	14.0
1931-1940	8.4	4.5	53.6	12.8	3.8	29.7	14.7	6.2	42.2	13.3	6.1	45.9	49.2#	11.6	23.6
1941-1950	7.6	2.9	38.2	15.6	4.2	26.9	16.1	7.0	43.5	16.3	4.3	26.4	55.4	9.9	17.9
1951-1960	7.2	5.5	76.4	12.8	5.7	44.5	15.3	3.9	25.5	14.8	5.8	39.2	50.1	10.6	21.2
1961-1970	9.7	3.8	39.2	13.2	6.5	49.2	12.7	4.3	33.9	18.6	5.8	31.2	54.2	10.9	20.1
1971-1980	16.7*	6.3	37.7	14.2	5.6	39.4	22.0*	4.5	20.5	17.8	4.2	23.6	70.7*	10.8	15.3
1981-1990	14.5*	5.2	35.9	13.3	4.6	34.6	24.0*	5.0	20.8	18.5	4.9	26.5	70.3*	6.1	8.7
1991-2000	12.5	4.6	37.1	14.4	4.6	31.9	16.7	7.1	42.5	16.8	5.9	35.1	60.4	10.3	17.4
1891-2000	10.9	5.8	53.1	13.8	5.7	41.4	17.0	6.8	40.0	16.0	5.7	35.8	57.7	12.0	20.8

* Significantly increasing, # Significantly decreasing



Figs. 2(a&b). Standardized anomaly of (a) LPS and (b) LPS Days during the monsoon months and season as a whole over the Indian region for period 1891-2000

respectively. Both the means are significantly higher than the long term mean 10.9. It shows that LPS Days have significantly increased during the decade 1971-80 and 1981-90.

In the month of July, mean LPS Days during the decade 1911-20 is 9.2 which is significantly lower than the long term mean 13.8. It shows that LPS Days have significantly decreased during the decade 1911-20.

In the month of August, the long term mean of the LPS Days is 17.0 and the mean LPS Days during the decades 1971-80 and during 1981-90 are 22.0 and 24.0 respectively which are significantly higher than the long term mean. This suggests that the LPS Days during these decades have significantly increased.

In September the decadal means of LPS or LPS Days are not significantly different from their respective long term means.

4.2. Decadal variation of LPS and LPS Days during the monsoon season

From the Table 9(a), it is noticed that the decadal mean of season's total number of LPS for the decade 1911-20 is significantly lower than the long term mean showing that LPS frequency had significantly decreased during the decade 1911-20.

The long term mean of the LPS Days for monsoon season is 57.7. The decadal mean of the monsoon season for the decade 1931-40 is 49.2 which is significantly less than the long term mean showing that the LPS Days during the decade 1931-40 have significantly decreased. The decadal means for 1971-80 and for 1981-90 are 70.7 and 70.3 respectively. These means are significantly higher than the long term mean. This shows that there is increase in the LPS Days during the monsoon season for the two decades, 1971-80 and 1981-90 though the frequency of LPS has not significantly increased during this period.

4.3. Normalized anomaly of the LPS and LPS Days

Normalized anomaly of the monthly and seasonal number of LPS and LPS Days over the Indian region are computed for the period 1891-2000 from the Tables 1 & 2 respectively. The series of the normalized anomaly of the LPS are shown in Fig.2 (a) and normalized anomaly of the LPS Days are shown in Fig. 2(b). The anomaly picture clearly depicts the increase in the LPS Days during the decades 1971-80 and 1981-90 for the months June & August and for the monsoon season as a whole.

5. Discussion

5.1. Frequency of LPS

From the study, it is seen that monthly frequency of LPS ranges between 0 to 6. It means the occurrences of LPS

during any monsoon month has not exceeded six. The instances for the number of LPS being 0 or 6 are very few. Monthly frequency of LPS is mostly concentrated between 3 and 4. Monthly average number of LPS ranges from 2.8 to 3.6. The seasonal frequency of LPS ranges from 9 to 18. In the hundred and ten years of study there are four events with 9 LPS and one event with 18 LPS. The average number LPS during the season is 13.

χ^2 test for normality shows that the frequency distribution of LPS for all the monsoon months and the season as a whole are normally distributed.

From Student's *t*-test it is seen that the number of LPS during August had significantly increased for the decade 1981-90. The frequency of LPS was significantly decreased during the monsoon season for the decade 1911-20.

There is no significant increase or decrease in the frequency of LPS during the recent decade, 1991-2000.

5.2. LPS Days

It is observed that monthly total number of LPS Days ranges from 0 to 32. In June, there are two occasions and in July, there is one occasion with zero LPS Days. Highest number of LPS Days *i.e.* 32 is observed in the month of August. In August and September there is not a single year with zero LPS Days. June has lowest average LPS Days and August has highest average LPS Days. Season's total number of LPS Days ranges between 32 and 82.

It is noticed from the study that the frequency distribution of LPS Days for all the monsoon months and season as a whole are normally distributed.

The *t*-test has brought out some significant results. The decadal mean LPS Days during the month of July for the decade 1911-20 are significantly below the long term mean, indicating that number of LPS Days significantly decreased during July for that decade. The season's decadal mean for 1931-40 is also significantly below long term mean.

It is also observed that the decadal means of 1971-80 and 1981-90 for the months June and August are significantly higher than their long term means and consequently the LPS Days during the monsoon season have also significantly increased during these decades.

The LPS Days have neither increased nor decreased significantly during the decade, 1991-2000.

6. Results and conclusions

A hundred and ten years statistical study of the low pressure systems over the Indian region reveals that,

(i) Monthly frequency of LPS ranges from 0 and 6. There is not a single year when monthly frequency of LPS is more than six. On an average three LPS in a month are more common. Average frequency of LPS during the monsoon months June to September are 2.8, 3.4, 3.6 and 3.2 respectively.

(ii) Total number of LPS for any year during the monsoon season ranges from 9 to 18. Average frequency of LPS during the monsoon season is 13.0.

(iii) Monthly total number of LPS Days ranges from 0 to 32. Average number of LPS Days during the monsoon months June to September are 10.9, 13.8, 17.0 and 16.0 respectively.

(iv) Total number of LPS Days for any year during the monsoon season ranges from 32 to 82 and average number of LPS Days during the monsoon season is 57.7.

(v) Occurrences of LPS and LPS Days are maximum during the month of August suggesting that activities of LPS are more in August as compared to the other monsoon months.

(vi) Frequency distribution of LPS shows that the number of occurrences of LPS during each of the monsoon months, June to September and for the monsoon season as a whole are normally distributed.

(vii) From the frequency distribution of LPS Days, it is seen that number of LPS Days occurring during the monsoon months June to September and also during the monsoon season are normally distributed.

(viii) The frequency of LPS has significantly increased for the month of August during the decade 1981-90. For the

monsoon season the frequency of LPS decreased significantly during the decade 1911-20.

(ix) The occurrences of LPS Days have significantly decreased in July during the decade 1911-20 and for the monsoon season during the decade 1931-40.

(x) The number of LPS Days have significantly increased for the months June and August for the decades 1971-80 and 1981-90. Consequently the occurrences of LPS Days have significantly increased during these decades.

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